Adaptive Shadow Maps

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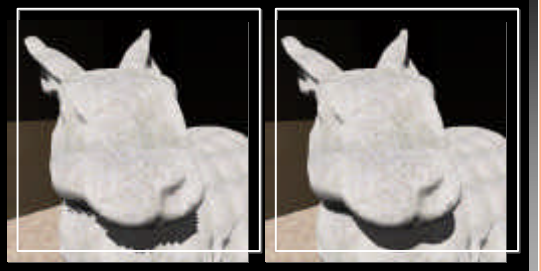
Shadow Maps

- Introduced by Lance Williams (SIGGRAPH 1978)
- Advantages
  - Flexible
  - Fast
  - Easy to implement
- One major disadvantage: aliasing
- Our solution: the Adaptive Shadow Map

Related Work

- Casting Curved Shadows on Curved Surfaces (Williams, 1978)
- Algorithms for Antialiased Cast Shadows (Hourcade and Nicolas, 1985)
- The Light Buffer: a Shadow Testing Accelerator. (Haines and Greenberg, 1986)
- Rendering Antialiased Shadows with Depth Maps (Reeves et al., 1987)
- Hierarchical Z-Buffer Visibility (Greene and Kass, 1993)
- Hierarchical Rendering of Trees from Precomputed Multi-Layer Z-Buffers (Max, 1996)
- Deep Shadow Maps (Lokovic and Veach, 2000)
- ...

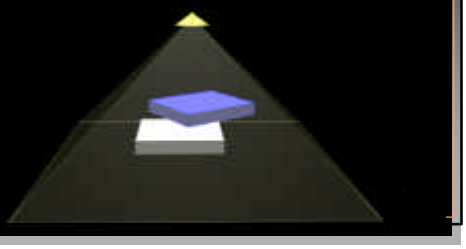
A Comparison



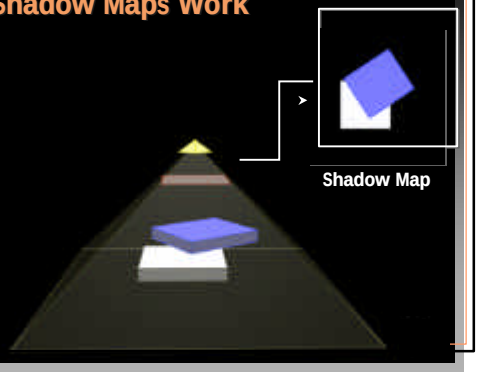
Conventional Shadow Map
(2048 x 2048 pixels)
16 MB Memory Usage

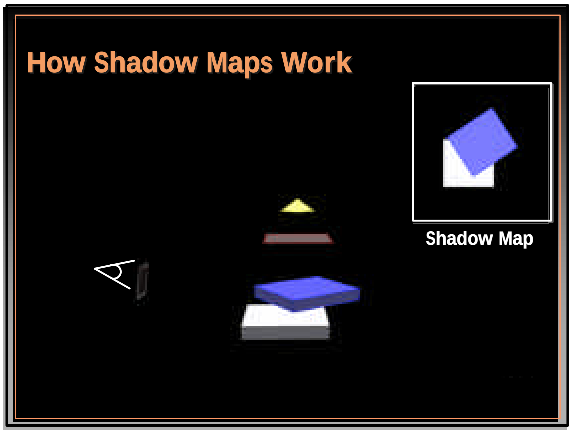
Adaptive Shadow Map
(Variable Resolution)
16 MB Memory Usage

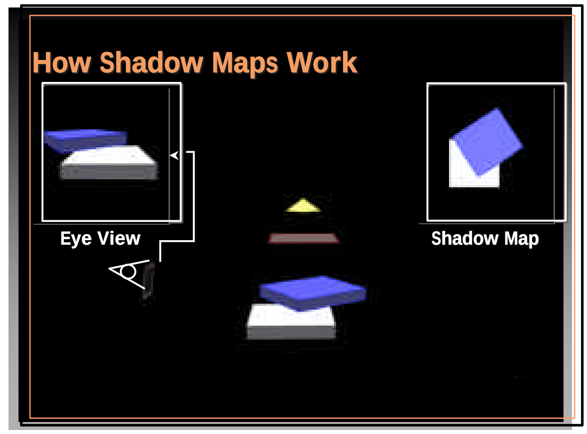
How Shadow Maps Work

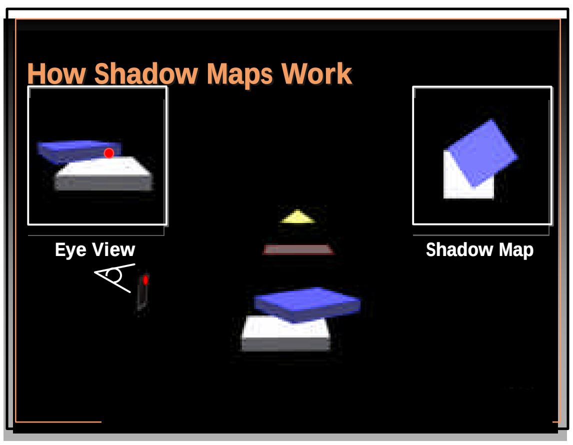


How Shadow Maps Work




How Shadow Maps Work
Shadow Map


How Shadow Maps Work
Eye View
Shadow Map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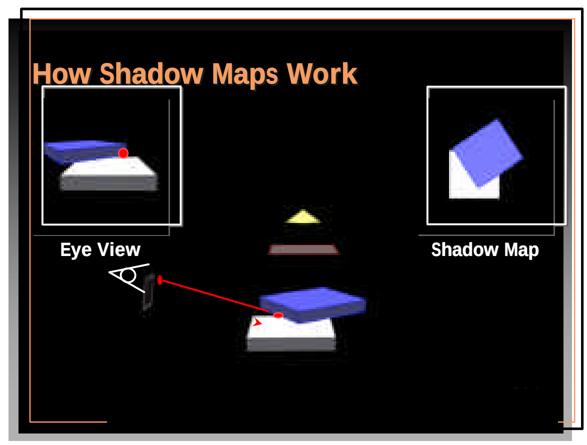
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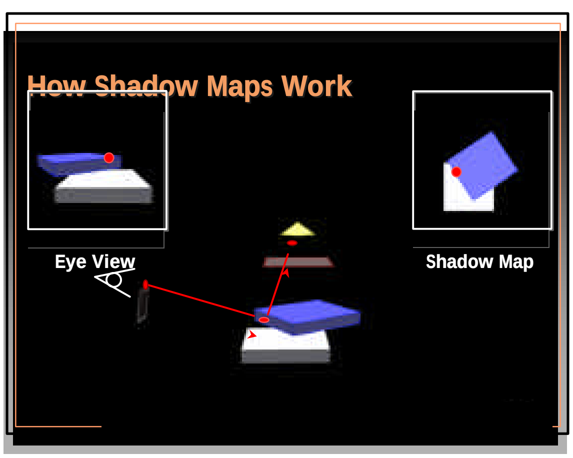
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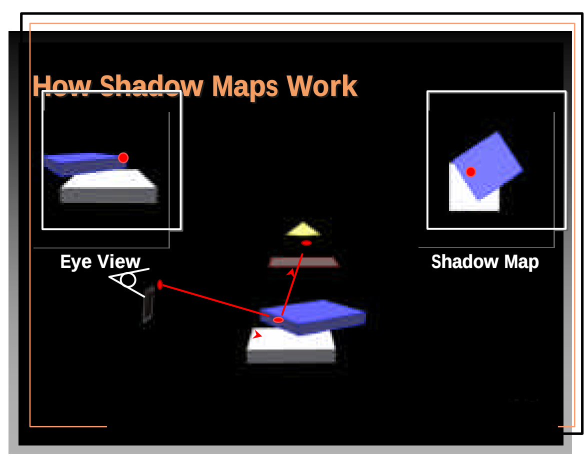
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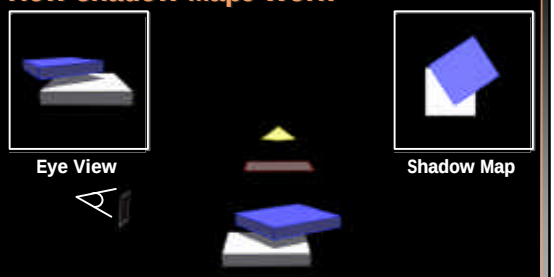
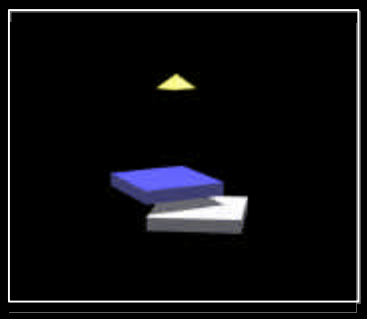
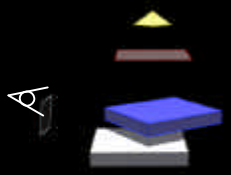


Aliasing (Distant)

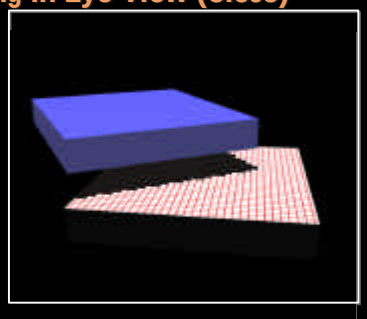
Aliasing in Eye View (Distant)



Aliasing (Distant)



Aliasing in Eye View (Close)



Motivation

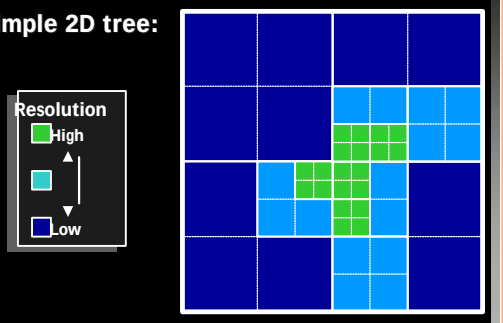
- **Shadow maps require too much tweaking**
  - Where to place light?
  - What resolution to use?
- **Goals:**
  - Address the aliasing problem
  - No user intervention
  - Interactive frame rate

Adaptive Shadow Maps

- **Idea:**
  - Refine shadow map on the fly
- **Goal:**
  - Shade each eye pixel with a different shadow map pixel
- **Implementation:**
  - Use hierarchical structure for shadow map
  - Create/delete pieces of shadow map as needed
  - Exploit fast rendering and frame buffer read-backs

Adaptive Shadow Map Data Structure

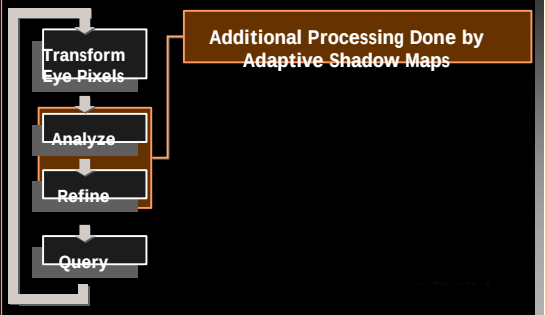
- **Simple 2D tree:**



Adaptive Shadow Map Characteristics

- **View-driven**
- **Constrained memory usage**
- **Progressive**
- **No manual intervention**
- **Usage same as conventional shadow map:**

Process Flow



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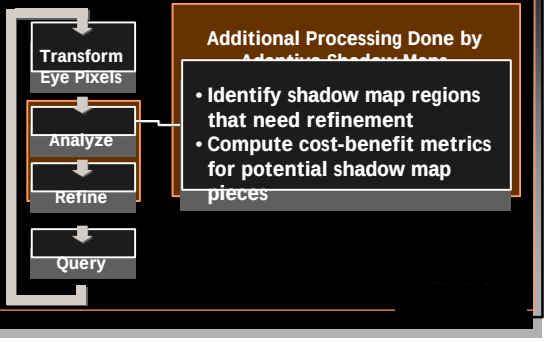

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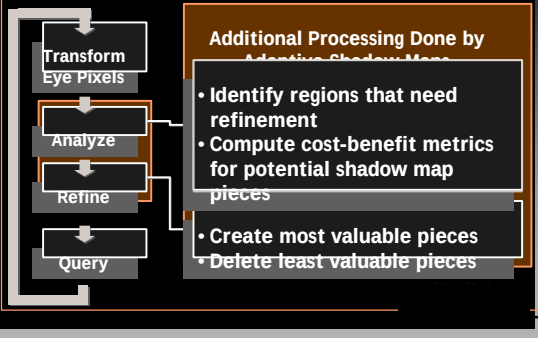
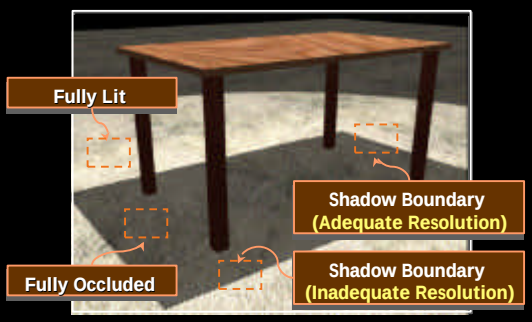


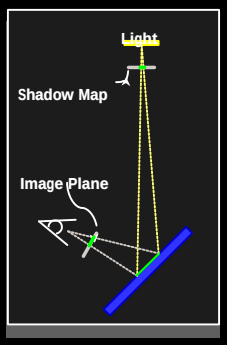
Where to Refine?



Resolution-Mismatched Edge Pixels

- **Eye view pixels that:**
  - Lie on shadow boundaries, *and*
  - Have a larger projected pixel size in the eye view than in the shadow map
- **Don't want to refine:**
  - Fully lit / fully occluded regions
  - Shadow boundary regions of adequate resolution

How Much to Refine?



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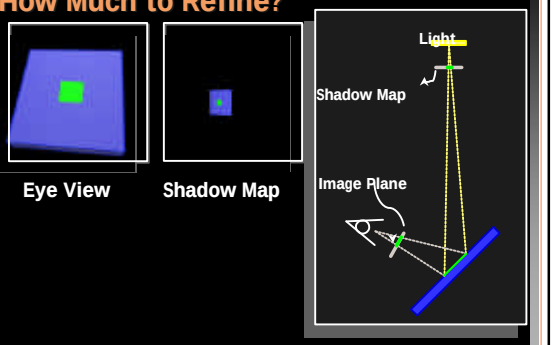

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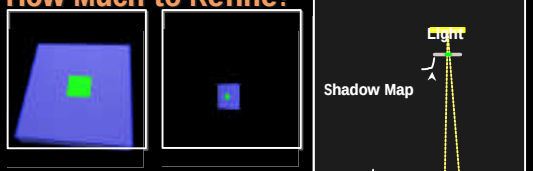
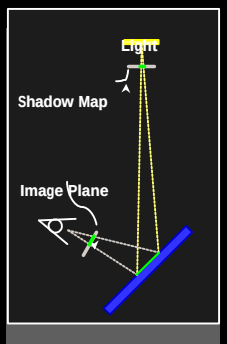


Goal:

Eye View Projected Area = Shadow Map Projected Area



Determining the Required Resolution

- **For each transformed eye view pixel :**

$N_{required}$ = Required Shadow Map Resolution

N_{eye} = Eye View Resolution

$$N_{required} = N_{eye} \times \frac{Eye\ View\ Pixel\ Projected\ Area}{Shadow\ Map\ Pixel\ Projected\ Area}$$

Refinement

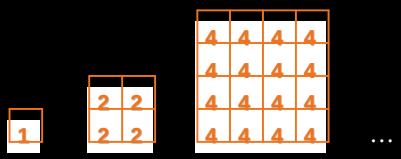
- **For each potential shadow map piece:**
  - $Max\ N_{required} > N_{current} \rightarrow$ refinement needed
  - Cost = $a\ (Max\ N_{required}) + b$
  - Benefit = number of resolution-mismatched edge pixels that would be resolved
- **Update data structure**

Determining the Projected Pixel Size

- **Use hardware texture-mapping features**
  - Mip-mapping
  - Trilinear / anisotropic filtering
- **Create uniform world texel size**
  - Compute projected size in eye view
  - Compute projected size in shadow map
  - Take ratio to determine if refinement is needed

Mip-map Specifics

- **Use alpha channel for calculations**
- **Define white mip-mapped texture**
- **Encode texture size in alpha channel:**

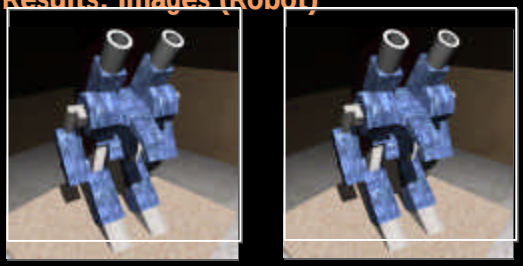


1 x 1 pixels | 2 x 2 pixels | 4 x 4 pixels

Mip-map Specifics (Cont'd)

- **For each polygon, pick texture coordinates that create a uniform texel size (in world space)**
- **Modulate with polygon color**
- **Turn on trilinear interpolation, anisotropic filtering**
- **Render scene**
- **On read-back, alpha value has mip-map size (estimate of projected pixel size)**
- **The graphics card does all the work!**

Results: Images (Robot)



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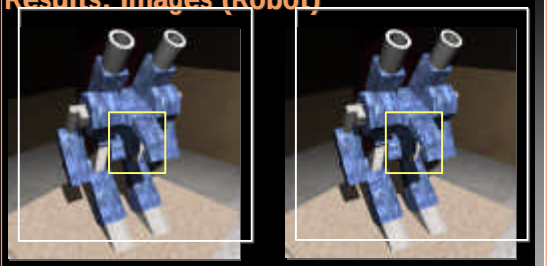

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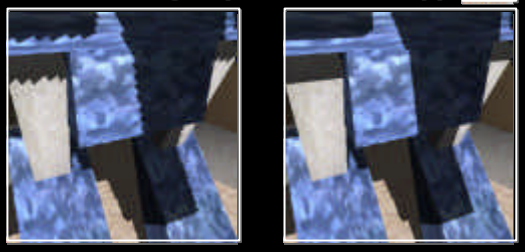
Results: Images (Robot Close-Up)



Conventional Shadow Map
16 MB Memory Usage

Adaptive Shadow Map
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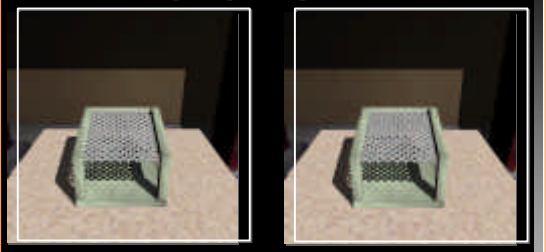
Equivalent Conventional Shadow Map Size:
65,536 ´ 65,536 Pixels

Results: Images (Mesh)



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(Variable Resolution)
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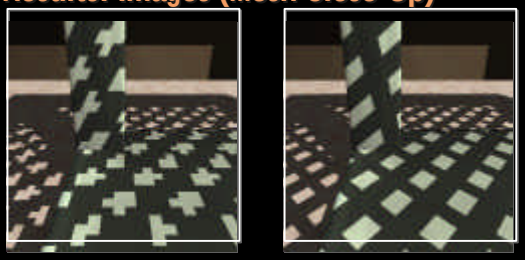
Results: Images (Mesh Close-Up)



Conventional Shadow Map
16 MB Memory Usage

Adaptive Shadow Map
16 MB Memory Usage

Equivalent Conventional Shadow Map Size:
65,536 ´ 65,536 Pixels

Results: Images (Mesh Close-Up)

Conventional Shadow Map
16 MB Memory Usage

Adaptive Shadow Map
16 MB Memory Usage

Equivalent Conventional Shadow Map Size:
524,288 ´ 524,288 Pixels

Results: Video

- Video filmed on a 1 GHz Pentium III with an NVIDIA GeForce2 Ultra graphics board
- Adaptive Shadow Map is on the left

Results: Video (First Part)

- Visualization of Hierarchical Structure

Results: Video (First Part)

- **Visualization of Hierarchical Structure**

Future Work

- **Integration with other approaches:**
  - Deep shadow maps
  - Percentage closer filtering
  - Soft shadow techniques
  - Perceptual metrics

Conclusion

- **Adaptive Shadow Maps**
  - Address aliasing
  - Hierarchical data structure
- **Features:**
  - View-driven
  - Constrained memory usage
  - Progressive
  - No manual intervention
  - Usage same as conventional shadow maps

Acknowledgements

- **Bruce Walter**
- **Eric Haines**
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Acknowledgements (Cont'd)

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Questions/Comments?